DOCUMENT RESUME

ED 178 304 SE 028 871

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TITLE Response Mode Effects on Computer Based Problem Solving. Report Series 1979.
INSTITUTION Iowa Univ., Iowa City. Computer Center.
PUB DATE 79
NOTE 15p.; For related document, see ED 154 831; Tables contain small print which may not reproduce well
AVAILABLE FROM Director, CAI Laboratory, Weeg Computing Center, The University of Iowa, Iowa City, IA 52242 (no price quoted)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Computer Assisted Instruction; *Educational Research; Educational Technology; *Higher Education; Logical Thinking; Mechanics (Process); Patterned Responses; *Problem Solving; Response Mode; *Thought Processes; Undergraduate Study

ABSTRACT

This response mode study attempts to determine whether different response modes are helpful or not in facilitating the thought process in a given problem solving situation. The Luchins Water Jar Test (WJT) used in this study illustrates the phenomena "Einstelling" (mechanization of response) because it does not require any specialized content information. The author discusses the results which indicate that there is no reason to prefer constructed response mode over multiple choice or numerical list modes when considering set formation and breaking out of set. (Author/SA)

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Response Mode Effects on Computer Based Problem Solving

The University
of Iowa
Iowa City, Iowa

Report Series 1978

CAI LAB

SE 028 871

RESPONSE MODE EFFECTS ON COMPUTER BASED PROBLEM SOLVING

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INTRODUCTION

Computer Assisted Instruction (CAI) allows students to respond using various devices, such as light pen, touch panel, joy stick or moveable crosshairs; the more commonly used keyboard-based modes such as constructed response, multiple choice, or alphanumeric code can be used as well. Because of this variety, response mode constitutes an instructional variable that may affect learning outcomes. This paper focuses on the use of keyboard based response modes.

Rationale

To date, most response mode investigations have been based on Programmed Instruction (PI) rather than CAI. Researchers have generally investigated two covert modes — reading a PI text, reading and thinking an answer — and two overt modes — constructed response, multiple choice. With technical or unfamiliar material, the constructed response mode has generally resulted in superior performance (Tobias, 1973). Tobias attributed the lack of response mode studies in CAI to the presumption that CAI consistandy employs overt modes. In view of the numerous overt modes in use in CAI, the potential effects that these response modes may have on learning outcomes merit attention.

Most response mode studies have used posttest achievement scores as the criterion measure. No studies that we know of have addressed the effect that various response modes may have on the development of thought processes during the instructional sequence. This study sought to determine whether different response modes facilitate or hinder the thought processes required in a given problem solving situation.

Research Focus

The problem solving task investigated in this study, the Luchins Water Jar Test (WJT), was chosen because it is established in the problem solving literature and does not require knowledge of a specific content area. The phenomenon that is of interest in the WJT is **Einstellung**, or mechanization of response. **Einstellung** is demonstrated by the successive repetition of a specific method of solution when more direct methods are available. Some people develop a mental "set" to solve a problem in the manner that they used previously, although that solution may be less appropriate than others or, more seriously, no longer workable. For these people, the effect of prior solution, more than the task at hand, becomes a major source of difficulty. A flexible problem solver resists such mechanization and employs the most direct methods of solution, that is, one requiring the minimal number of intervening states. Throughout this paper, solutions which exhibit machanization or **Einstellung** will be referred to as **Einstellung** solutions, while those which are flexible or direct will be referred to as direct solutions.

Response Mode Question

The various keyboard-based response modes can be viewed as languages which the student uses to interact with the instructional program. Response modes serve to transmit the messages which result from the thought processes; they may, however, serve to structure the thought processes as well. If response modes are considered to be alternative languages that allow instructional dialogue between the student and the com-

puter, it follows that facility in using a given response mode may influence degree of mechanization in computer-based problem solving situations as represented by the WJT. The response modes investigated where mnemonic code (Code), multiple choice (MC), numberical list (List), and constructed response (CR). Our assumption was that response modes that more closely approximate natural language would be more facilitative of flexible thought and would therefore, lead to less mechanization in problem solving.

The WJT consist of three kinds of problems:

Set — solvable only by the original formula and designed to produce a mental set predisposing the use of the original formula in subsequent problems;
Criticals — solvable by the original formula or by a shorter method and designed to test susceptibility to the mental set established in the first problems, and
Extinction — not solvable by the original formula, therefore requiring a shift in method to reach solution; designed to measure ability to overcome the set established in the preceeding problems.

Hypotheses

In the WJT, mechanization, as it applies to Critical and Extinction problems, is operationally defined as the continued attempt to use the method of solution which was correct in the Set problems. We hypothesized that constructed response, code, list, and multiple choice would contribute to the degree of mechanization in the stated order. Mechanization would be demonstrated by the following indices:

1. A greater use of **Einstellung** than direct solutions in Critical problems.
2. More no solutions in the Extinction problems resulting from inappropriate attempts to use the **Einstellung** method.
3. Shorter latencies in both Critical and Extinction problems due to the tendency to use the **Einstellung** method initially.
4. Less total time spent in Critical problems since constructing and implementing an alternative direct solution would require more time than simple repetition.
5. Greater total time spent in Extinction problems since the initial use of the **Einstellung** method would lead to a false start.
6. More steps to solution in the CR, Code, and List modes.

PROCEDURE

Participants

Participants were recruited from an undergraduate education course, Fundamentals of Audiovisual Techniques, at The University of Iowa in the 1976 fall semester. These students volunteered to become acquainted with the use of computers in instruction. Sessions were held over a two week period and three to seven students were present at each session. Of the 73 students who participated, three failed to complete the problem sequence. Data from six additional students were discarded, since these students did not correctly solve the last two Set problems, thereby precluding the assumption that they had in fact formed a set which would be tested in the subsequent Critical and Extinction problems.

Materials

The Luchins water jar problems were presented on cathode ray tube (CRT) terminals in The University of Iowa Computer Assisted Instruction Laboratory. For each problem, the student was verbally presented with jars of three different capacities and was instructed to obtain a fourth quantity by filling, transferring, or emptying the contents. A prototype is : "You are given three jars, A, B, and C, which hold 11, 25, and 5 quarts. By measuring back and forth using only these three jars, obtain 4 quarts." This problem may be solved in the following manner: Fill jar B, pour from jar B into jar A, pour from jar B into jar C, empty jar C, pour from jar B into jar C, the solution is in Jar B. This procedure could be represented by the formula "B-A-2C." The problem series presented is listed in Table 1.

TABLE 1
PROBLEM SERIES USED

PROBLEM #	PROBLEM	SOLUTIONS*	TYPE
1	11-25-5 get 4	E	set
2	21-127-3 get 100	E	set
3	14-163-25 get 99	E	set
4	18-43-10 get 5	E	set
5	9-42-6 get 21	E	set
6	20-59-4 get 31	E	set
7	23-49-3 get 20	E or D	critical
8	15-39-3 get 18	E or D	critical
9	28-76-3 get 25	D	extinction
10	18-48-4 get 22	E or D	critical
11	14-36-8 get 6	E or D	critical
12	8-21-4 get 7	E	set
13	40-118-18 get 62	D	extinction

* E indicates Einstellung Method
D indicates Direct Method

These problems were solved using one of four response modes:

Code—a mnemonic code corresponding to possible steps, such as "BIA" for "pour the contents of B into A";
List—a numerical list corresponding to possible steps, such as "3" for the step "fill jar C";
Constructed Response—open-ended, natural language response, such as "fill jar A."
Multiple Choice—a list of solution equations such as "B-A-2C" with three other possible equations.

A comparison of the List and Code commands with their general constructed response equivalent appears in Table 2.

TABLE 2

INPUT COMMANDS FOR LIST AND CODE RESPONSE MODES

LIST	CODE	COMMAND
1	FA	Fill Jar A
2	FB	Fill Jar B
3	FC	Fill Jar C
4	AIB	Pour the contents of A into B
5	AIC	Pour the contents of A into C
6	BIA	Pour the contents of B into A
7	BIC	Pour the contents of B into C
8	CIA	Pour the contents of C into A
9	CIB	Pour the contents of C into B
10	EA	Empty Jar A
11	EB	Empty Jar B
12	EC	Empty Jar C
13	SA	Solution is in Jar A
14	SB	Solution is in Jar B
15	SC	Solution is in Jar C
16	NS	No Solution

In all problems a no solution option was available. A display at the top of the screen showed jar capacities and current quanitities held which were updated with each command. Students were advanced to the next problem when they successfully solved the problem or chose the no solution option.

Upon arrival, students were given a tour of the CAI Lab and an opportunity to become familiar with the CRT keyboard. Students were randomly assigned to one of four response mode groups: code, multiple choice, list, or constructed response. A five-minute introduction to the water jar problems was presented at the CRT, followed by instructions on using the response mode assigned.

All subjects received the same sequence of problems which took from 20-40 minutes to complete. Subjects who solved either problem 5 or problem 6 by the **Einsellung** method were considered to have formed set. This was a departure from the often employed criterion that requires the solution of both problems 5 and 6 by the **Einstellung** method to consider the subject as having formed set. At the conclusion of the problem series, each particpant worked through three sample CAI programs consisting of a sample from a law module, a graphic demonstration, and a math drill and practice program.

RESULTS

TABLE 3

ANALYSIS OF VARIANCE OF E-TYPE SOLOUTION IN CRITICAL PROBLEMS

SOURCE	DF1	DF2	F	SIGNIFICANCE
MODE	3	28.72	.40	
ITEM	2.76	166.87	10.26	.000006
ITEM X MODE	8.29	166.87	3.84	.000329

As indicated in Table 3, the measure of susceptibility to set was significant. Tests of simple effects revealed a significant difference between response modes only in problem 7, where the MC group used significantly more **Einstellung** solutions than the List (p .004) or (p .0004) group.

Method of Solution

TABLE 4

FORMATION OF SET IN CRITICAL PROBLEM*

GROUP	PROBLEM 7	PROBLEM 8	PROBLEM 10	PROBLEM 11
Code	.43 (.99)	.57 (.84)	.25 (.43)	.12 (.33)
Multiple Choice	.72 (.44)	.16 (.37)	- 0 -	- 0-
List	.25 (.43)	.25 (.43)	.25 (.43)	.12 (.33)
Constructed Response	.14 (.34)	.28 (.45)	.14 (.34)	.14 (.34)

*Note: Scale in criticals represent mean number of Einstellung type solutions.
Scale in extinctions represents mean number of Direct solutions.
Numbers in parentheses indicate standard deviations.

From inspection of the means in Table 4, it can be seen that the above results derive from an initial high use of **Einstellung** solutions in problem 7 by the MC group followed by a total decline in that use; other response mode groups exhibited a more consistent performance.

TABLE 5

ANALYSIS OF VARIANCE OF D-TYPE SOLUTIONS IN EXTINCTION PROBLEMS

SOURCE	DF1	DF2	F	SIGNIFICANCE
MODE	3	27.24	.08	.980000
ITEM	1	60	81.84	.000000
ITEM X MODE	3	60	3.98	.011779

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The analysis of variance for the number of direct solutions in Extinction problems, which is the measure of ability to overcome set, also yielded a significant item by mode interaction as shown in Table 5. Between simple effects, follow-up tests indicated a significant difference between response modes for problem 13 ($p<.003$). Pairwise comparisons indicated that on problem 13 the MC group employed significantly more direct solutions than any of the other three groups. Within simple effects follow-up tests revealed significant differences between problems 9, where more direct solutions were used, and 13. The means and standard deviations for these data are given by group in Table 6.

TABLE 6

ABILITY TO OVERCOME SET IN EXTINCTIONS*

GROUP	PROBLEM 9	PROBLEM 13
Code	.93 (.24)	.18 (.39)
Multiple Choice	1.00 (0)	.77 (.41)
List	1.00 (0)	.37 (.48)
Constructed Response	1.00 (0)	.42 (.49)

*Note: Scale in criticals represents mean number of Einstellung type solutions.
Scale in extinctions represents mean number of Direct solutions.
Number in parenthesis indicate standard deviations.

TABLE 7

ANALYSIS OF VARIANCE FOR TIME TO FIRST RESPONSE FOR CRITICAL PROBLEMS

SOURCE	DF1	DF2	F	SIGNIFICANCE
MODE	3	31.216	1.88	
ITEM	1.83	110.088	6.22	.000688
ITEM X MODE	5.50	110.088	4.03	.001515

Response Latency

A significant item by mode interaction in the anaylsis of variance on "time to first response in Criticals" is shown in Table 7. Between simple effects, follow-up tests indicated a significant difference between modes on response latency for problems 7 and 8. Pairwise comparisons indicated that the MC group experienced a significantly longer latency than the Code and List groups in these two problems.

TABLE 8

ANALYSIS OF VARIANCE FOR TIME TO FIRST RESPONSE IN EXTINCTION PROBLEMS

SOURCE	DF1	DF2	F	SIGNIFICANCE
MODE	3	30.83	.633	.882978
ITEM	1	80	30.420	.000001
ITEM X MODE	3	80	.300	.826000

As indicated by Table 8, the item by mode interaction on the analysis of variance for "time to first response on Extinction problems" was not significant. The analysis of the mode main effect failed to achieve significance, while the problem main effect was clearly significant. As can be seen from Table 9, latency for all modes was longer for problem 13 than for problem 9.

TABLE 9

MEAN TIME IN SECONDS FOR TIME TO FIRST RESPONSE AND TOTAL TIME IN PROBLEM

CRITICAL PROBLEMS – LATENCY

GROUP	PROBLEM 7	PROBLEM 8	PROBLEM 10	PROBLEM 11
Code	10.18 (6.90)	12.68 (6.91)	11.12 (7.14)	20.25 (16.83)
Multiple Choice	22.27 (9.83)	18.56 (8.24)	10.56 (6.80)	13.61 (9.88)
List	12.37 (5.36)	11.68 (5.98)	13.18 (8.19)	14.87 (11.56)
Constructed Response	14.84 (11.12)	17.00 (8.61)	12.72 (7.14)	31.07 (28.86)

EXTINCTION PROBLEMS – LATENCY

GROUP	PROBLEM 9	PROBLEM 13
Code	16.16 (16.70)	46.17 (47.94)
Multiple Choice	16.61 (16.18)	51.38 (26.21
List	29.75 (61.08)	78.00 (82.23)
Constructed Response	14.50 (12.08)	54.21 (42.97)

CRITICAL PROBLEMS – TOTAL TIME

GROUP	PROBLEM 7	PROBLEM 8	PROBLEM 10	PROBLEM 11
Code	38.93 (26.70)	42.24 (14.00)	57.43 (40.38)	84.12 (67.12)
Multiple Choice	24.90 (10.75)	20.56 (8.34)	12.27 (8.96)	22.33 (29.27)
List	36.62 (14.30)	46.56 (15.15)	43.88 (14.50)	45.50 (36.09)
Constructed Response	88.36 (20.77)	109.86 (86.69)	72.71 (25.21)	75.57 (26.21)

EXTINCTION PROBLEMS – TOTAL TIME

GROUP	PROBLEM 9	PROBLEM 13
Code	76.37 (110.39)	107.68(126.76)
Multiple Choice	23.88 (13.00)	58.83 (27.30)
List	77.31 (116.83)	186.87 (89.14)
Constructed Response	53.57 (31.75)	324.92 (347.58)

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TABLE 10

ANALYSIS OF VARIANCE FOR TOTAL TIME IN PROBLEM FOR CRITICAL PROBLEMS

SOURCE	DF1	DF2	F	SIGNIFICANCE
MODE	3	29.10	30.225	
ITEM	2.24	134.21	3.260	.036044
ITEM X MODE	6.71	134.21	2.980	.00748

Total Time

A significant item by mode interaction was present in the analysis of variance for "total time in problem for Criticals", as shown in Table 10. Between simple effects, follow-up tests indicated a significant difference between response modes for all Critical problems. Pairwise comparisons demonstrated that the MC mode differed significantly ($p<.05$) from the other modes in all problems except problems 7 where the MC vs. Code comparison approached ($p<.09$). The means in Table 9 show that the shortest time solving the problem was spent by the MC group, the longest time by the CR group, and similar, intermediate times by the Code and List group.

TABLE 11

ANALYSIS OF VARIANCE FOR TOTAL TIME IN PROBLEM FOR EXTINCTION PROBLEMS

SOURCE	DF1	DF2	F	SIGNIFICANCE
MODE	3	25.18	14.26	
ITEM	1	60	21.93	.000017
ITEM X MODE	3	60	3.96	.012164

The item by mode interaction was significant in the analysis of variance for "total time spent in problem for Extinction problems", as shown in Table 11. Between simple effects, follow-up tests indicated a significant difference between response modes on both problems 9 and 13. Pairwise comparisons indicated that the MC group differed significantly from the CR group on both problems. The comparisons between MC and both the List and Code groups approached significance in problem 9 and were significant in problem 13. As can be seen in Table 9, the general pattern established in "total time in problem in Criticals" held for extinctions; the shortest time was spent by the MC group, similar, intermediate times by the List and Code groups, and the longest time by the CR group.

TABLE 12

ANALYSIS OF VARIANCE OF TOTAL STEPS IN CRITICAL PROBLEMS

SOURCE	DF1	DF2	F	SIGNIFICANCE
MODE	2.00	26.38	.413	.666173
ITEM	2.29	98.53	7.60	.000441
ITEM X MODE	4.58	98.53	1.28	.282623

The MC group was omitted from the analysis of variance of the "total number of steps to problem completion" since this mode did not require input on a per-step basis.

Number of Steps

As indicated in Table 12, the item by mode interaction was not significant for the "analysis of variance for total number of steps in Critical problems" based on the Code, List, and CR modes. The mode main effect was not significant. The means displayed in Table 13 indicate that across modes, problems 7 and 11 took fewer steps than problems 8 and 10.

TABLE 13

MEAN NUMBER OF STEPS USED BY CODE, LIST AND CONSTRUCTED RESPONSE RESPONSE MODE GROUPS

CRITICAL PROBLEMS

GROUP	PROBLEM 7	PROBLEM 8	PROBLEM 10	PROBLEM 11
Code	4.75 (1.78)	5.87 (1.40)	6.87 (3.46)	5.00 (2.62)
List	4.25 (1.43)	5.81 (0.94)	5.50 (0.93)	5.12 (4.28)
Constructed Response	3.71 (1.09)	7.42 (3.29)	5.92 (0.88)	4.57 (3.31)

EXTINCTION PROBLEMS

GROUP	PROBLEM 9	PROBLEM 13
Code	4.93 (4.58)	9.87 (9.49)
List	4.68 (2.11)	7.87 (5.38)
Constructed Response	3.78 (1.47)	11.50 (12.24)

NOTE: Number in parenthesis indicate standard deviations.

The item by mode interaction in the "total steps to completion in Extinction problems" failed to achieve significance, as shown in Table 14. The mode main effect was not significant. The analysis of the problem main effect was significant, indicating that across modes there was a difference in the total number of steps to completion between problems 9 and 13, the latter requiring more steps.

TABLE 14

ANALYSIS OF VARIANCE FOR TOTAL STEPS IN EXTINCTION PROBLEMS

SOURCE	DF1	DF2	F	SIGNIFICANCE
MODE	2	24.24	.409	.668783
ITEM	1	43.00	12.950	.000822
ITEM X MODE	2	43.00	.81	.450719

DISCUSSION

Method of Solution

Results failed to support the hypothesized differences in susceptibility to set by the response mode groups. Analyizing performance on the Critical problems as a group, the Code and CR groups were not more impervious to set than the List and MC groups as anticipated. However, the MC group overwhelmingly used the **Einstellung** method in problem 7, an indication of set formation, but favored more direct methods in problems 10 and 11. While initially superior, the Code, List, and CR groups' use of direct methods was later inferior to the MC group's use of these methods.

The MC mode group was more consistent in overcoming set as measured by the use of direct solutions in the Extinction problems. All four groups used the direct method almost exclusively in problem 9 but decreased that use in problem 13. However, the MC group's use decreased to a lesser degree than did the other groups. These results appear to indicate that problems 9 and 13 were not equally difficult, and that the difference in item difficulty had a more powerful effect on the Code, CR, and List then on the MC mode.

Response Latency

We assumed that mechanization would be accompanied by shorter latencies in the first response and would preclude consideration of other methods, thus leading to the repetition of the first step on both Critical and Extinction problems. For the Critical problem series, contradictory results were found. That is, the MC group moved from the use of **Einstellung** solutions in problems 7 and 8 to direct solutions in 10 and 11. The later use of direct solutions was accompanied by shorter, not longer, latencies. The hypothesized longer latencies for the MC group were observed in problems 7 and 8, but not in 10 and 11 where the MC group exhibited the lowest mean times.

Total Time

The MC group, which exhibited the least mechanization in "criticals", took the shortest total time to solve the problems; the longest total time was shown by the CR group and similar intermediate times by List and Code groups. It should be noted that in most cases the time to first response for the MC mode also constituted the total time, and that the long CR total reflects extended keyboard interface.

The variation in the "total time in problem on Extinctions" supports the previous indication that problems 9 and 13 were not of equal difficulty. The means for the Code, MC, and List groups were approximately twice as large for 13 as for 9; for the CR group, the ratio was six times greater. However, the CR Group also had greater variance than the other groups. This may indicate that some students in the CR group, frustrated when using inappropriate solutions, thought longer or hesitated more.

The MC group spent less "Total time in problem on Extinctions", while maintaining less susceptibility to set. While this result too, may be attributed to input demands, it also may be due to the differing demand characteristcs of the response modes. Recognition or selection of a solution, as in the MC mode, may lead to more direct solutions, and shorter latencies than constructed response mode.

Number of Steps

Number of steps constituted the unit for measuring efficiency in solution: a direct solution used fewer steps than a meanized one. No significant differences in number of steps were observed. The MC group data were not amenable to analysis on this measure.

In considering method of solution in Criticals and Extinctions, latency to first response, and total time in problem, it appears that students using the MC mode exhibited superior performance. While the MC group showed set formation in problem 7, this quickly disappeared in following problems. The MC group spent less time in problems and, based on observation of the subjects, MC was the easiest mode to use. No differences of note were observed among the other three groups.

Results suggest that the multiple choice response mode led to better student performance. We, of course, acknowledge that solutions to real world problems are not often found among multiple choice options. In designing instructional materials, however, the multiple choice mode is often used, particularly in CAI. Because this mode, as well as constructed response and numerical list are used, it is of interest to instructional designers to identify the effects that these modes may have exhibited in and of themselves in the problem solving process.

We have operated under the assumption that mechanization is an undesirable approach to problem solving. In the real world, however, mechanization does have beneficial effects in certain situations. When a problem solver is faced with a homogeneous class of problems for which a solution exists, application of the mechanized solution may be very appropriate. The undesirable effects of mechanization are most pronounced in situations where problems that appear to belong to a single class, differ to just such an extent as to make a prior solution method inefficient or unworkable. Such variation in problem type is seen with great frequency in instructional and naturalistic settings. In such situations mechanization or set consists of an overgeneralization of a solution and/or a failure to discriminate between problems of different types or class. In discussing student performance it is necessary to bear in mind that the WJT constitutes a specific subset of problem solving situations. The primary interest is in mechanization of solution method in a mathematical problem solving series. Set must be considered debilitating when use of a single viable method in a series of problems causes the learner to perseverate on this method, thus precluding the development of alternate methods in subsequent problems even though the original method no longer leads to solution.

Within the limitations of generalizations, the results of this study suggest no reason for preferring constructed response mode over MC or List modes when considering set formation and ability to break out of set. Instructional intent will, of course, often limit the range of suitable response modes.